UNIT ONE

CHAPTER 1

INTRODUCTION

1.1 Historical perspective

Materials play an important role in our life. This is because every segment of our everyday lives – such as transportation, housing, clothing, medicine, communication, recreation and food production – is influenced by materials in one way or other. Materials are probably more deep rooted in our culture. Historically, the development and advancement of societies have been intimately connected to the means ability to produce materials to fill their needs. This is why early civilizations have been named by the level of their materials development (Stone age, Bronze age, Iron age etc.).

In the very early ages humans have had only a very limited number of materials such as stone, wood, clay, skins etc. As time passes they discovered techniques for producing materials that had properties superior to the earlier ones. Pottery and various metals are examples of this. Later they discovered that the properties of material could be altered by adding other substances and also by heating. At this point onwards material utilization was totally a selection procedure that involved choosing the best material for the application by studying its characteristics. After that scientists came to understand the relationship between structural materials and their properties. This acquired knowledge over the past 100 years led scientists to discover tens of thousands of different materials, which have specialised characteristics that meet the needs of our modern society. These includes metals, plastics, glasses, fibres etc.

The accessibility of suitable materials made significant advancement in the development of many technologies which make human society more comfortable. For example, automobiles would not have been possible without the availability of inexpensive steel. Another example is that electronic devices rely much upon materials known as semiconductors.

1.2 What is materials science

Materials science is the study of properties of solid materials and how those properties are determined by a materials composition and structure.

Or

Materials science involves investigating the relationships that exist between the structures and properties of materials.

This branch grew out of an amalgam of solid state physics, metallurgy and chemistry, since the rich variety of properties of materials cannot be understood within the context of any single discipline. With a basic understanding of the origins of properties, materials can be selected or designed for an enormous variety of applications, ranging from structural steels to microchips. Materials science is therefore important to engineering activities such as electronics, aerospace, telecommunications, information processing, nuclear power and energy conversion. These disciplines come under materials engineering. Materials engineering deals with designing or engineering the structure of a materials to produce a predetermined set of properties on the basics of structure-property correlations. The role of materials scientists is to develop new materials where as a materials engineer is called upon to create new materials or to develop techniques for processing materials.

In the above discussion two terms "structure" and properties deserve some explanation.

Structure of a material refers to the arrangement of its internal components. Subatomic structure involves electrons within the individual atoms and interactions with the nuclei. On the atomic level, structure encompasses the organisation of atoms or molecules relative to one another. The next larger structural realm is termed microscopic meaning that which is subject to direct observation using microscopes. This is actually the totality of large group of atoms forming the structure. The structure that may be viewed with naked eye are termed macroscope.

Property of materials implies the behaviour exhibited by the materials when subjected to external stimulus. Important properties of materials may be grouped into six different categories: mechanical, electrical, magnetic and deteriorate. For each category there is a characteristic type of stimulus capable of producing responses. Mechanical properties relate deformation to an applied force which include elasticmodulus and strength. When the stimulus is electricfield deformation occurs which gives properties such as electrical conductivity and dielectric strength. The thermal properties of materials can be represented in terms of heat capacity and thermal conductivity. Here the stimulus is heat. Magnetic properties demonstrate the response of a materials to the application of magnetic field. For optical properties, the stimulate is electromagnetic radiation; refractive index and reflectivity are representative optical properties. The deteriorative characteristics relate to the chemical reactivity of materials. It may be remembered that the structure of materials will depend upon how it is processed and materials performance will be a function of its properties. The interrelationship between processing, structure, properties and performance is depicted in the schematic illustration. (Figure 1.1)

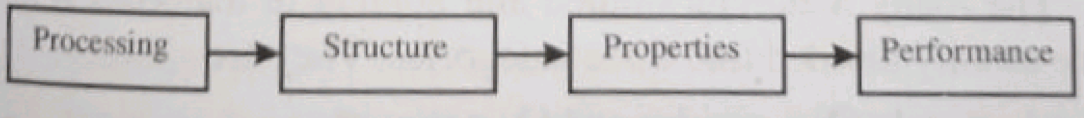

Figure 1.1: The four components of the discipline of materials science and their interrelationships.

1.3 Why do we study materials science

Human society using tens of thousands of devices for their lives. For making such devices different types of materials are required. For example the main materials used for constructing a train is not suitable to construct a plane or an integrated chip. So first and fore most requirement is selecting the right material from the many thousands that are available. There are several criteria on which the final selection is based. First of all, the in-service conditions of the device must be characterised. This will specify the properties required by the material. We select a material which obeys maximum number of properties or ideal combination of properties. Sometimes it may be necessary to compromise. For example strength and ductility. Normally, a material having high strength will have only limited ductility. In such cases a reasonable compromise between the two.

The second selection consideration is due to deterioration of material properties that may occur during service operation. For example significant reductions in mechanical strength may result from exposure to elevated temperatures or corrosive environments.

Finally the consideration is that of economics: what will be the finished product cost. A material found suitable obeying almost all properties required may be expensive. Again some compromise has to be made.

To meet all these requirements materials must be studied in depth. This will be done by materials scientists and engineers.

1.4 Classification of materials

The many materials studied and applied in materials science are usually divided into three categories. They are

(1) metals (2) ceramics and (3) polymers.

This classification is based primarily on chemical make up and atomic structure. Most materials fall into one group or another, although there are some intermediates. In addition, there are combinations of two of more of the above three basic material classes. They are called composites materials. Above all there is another classification called advanced materials such as semiconductors, biomaterials, smart materials and nano engineered materials.

1. Metals

Materials in this group are composed of one or more metallic elements such as iron, aluminium, copper, titanium, gold and nickel and often also non metallic elements (carbon, nitrogen and oxygen) in relatively small amounts.

Atoms in metals and their alloys are arranged in a very orderly manner in comparison to the ceramics and polymers and are relatively dense.

Properties

1. These materials are relatively stiff and strong hence are ductile and are resistant to fracture.

   Ductile means capable of large amounts of deformation without fracture.
2. Metals are good conductors of electricity and heat and are not transparent to visible light. This property is due to large number of non-localised electrons in these materials, that is these electrons are not bound to particular atoms.
3. When polished metal surface exhibits lustrous appearance.
4. Some of the metals (Fe, CO, and Ni) have desirable magnetic properties.

2. Ceramics

A ceramic is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and hardened by heating to high temperatures. i.e., ceramics are componds between metallic and non-metallic elements. Most of them are okides, nitrides and carbides. Some common ceramic materials are aluminium oxide (Al_2O_3) aluminium silicon dioxide (SiO_2 – silça) Silicon carbide (SiC), Silicon nitride (Si_3N_4) and clay materials and cement.

Properties

1. Ceramic materials are relatively stiff and strong comparable to those of metals.
2. Ceramic are typically very hard, but extremely brittle and highly susceptible to fracture.
3. These materials are insulators. i.e., they do not conduct heat or electricity. In other words they have low thermal and electrical conductivities.
4. These are more resistant to high temperatures and harsh environments than metals and polymers.
5. Cermics may be transparent, translucent or opaque.
6. Some of the oxide ceramics (Fe_3O_4) exhibit magnetic behaviour.

3. Polymers

Polymer, any of a class of natural or synthetic substances composed of very large molecules called molecules that are multiples of simpler chemical units called monomers. The familiar plastic and rubber materials are examples. Most of them are organic compounds that are chemically based on carbon, hydrogen and other non-metallic elements (O, N and Si). Carbon atoms are the back bone of the large molecular structure of polymers. Some of the common and familiar polymers are polyethylene (PE), nylon, polyvinyl chloride (PVC), Polycarbonate (PC), Polystyrene (PS) and silicone rubber.

Properties

1. Polymers are not as stiff nor as strong as other materials.
2. They are extremely ductile and pliable (plastic). This means that polymers can be easily formed into complex shapes.

3. They are relatively inert chemically and unreactive in a large number of environments.
4. These materials have low densities.
5. They have low electrical conductivities and are non-magnetic. One major drawback of polymers is their tendency to soften and or decompose at moderate temperatures which limits their use in some instances.

4. Composites

Composites are materials made up of two or more basic materials (metals, ceramics and polymers). The aim of constructing composites is to achieve a combination of properties that is not displayed by a single material. By doing so we can incorporate the best characteristics of each of basic materials. There are large number of synthetic (manmade) composites are available in the market produced by different combinations metals, ceramics and polymers.

One of the most common and familiar composites is fibre glass, in which small glass fibres are embed within a polymeric material (normally an epoxy or polyester). The glass fibres are relatively strong, stiff and also brittle, where as the polymer is ductile, weak and flexible. Thus the resulting fibre glass is relatively stiff, strong, flexible and ductile. In addition it has a low density.

Another important composites is the carbon fibre reinforced polymer (CFRP). In this carbon fibres are embedded within a polymer. This composites is stiffer and stronger than the glass fibre-reinforced materials. Hence they are more expensive. The CFRP composites are used in some aircrafts and aerospace applications, as well as high-tech sporting equipment like bicycles, golf clubs, tennis rackets and snow-boards. In this book we discuss only synthetic composites. Two naturally occurring composites materials are wood and bone.

1.5 Advanced materials

Materials that are utilised in high technology applications are termed as advanced materials. By high technology we mean a device or product that operates or functions using relatively intricate and sophisticated principles. Examples are electronic equipments such as camcorders, CD, computers fibre optic systems, space craft, aircraft and military rocketry. These advanced materials are typically traditional materials whose properties have been enhanced also newly developed high performance materials. All are making out from our three basic materials and normally are expensive. Advanced materials include semiconductors, biomaterials, smart materials and nano engineered materials. **Smart materials and nano engineered materials are termed as "materials of the future".**

Semiconductors

Semiconductors have electrical properties that are intermediate between the conductors (metals and alloys) and insulators (ceramics and polymers). Further the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of imparity atoms, for which the concentrations may be controlled over very small spatial regions. Semiconductors paved the way to advent integrated circuits that revolutionized the electronic and computer industry over past several decades.

Biomaterials

A biomaterial is a substance that has been engineered to interact with biological systems for medical purpose. As a science biomaterials is about fifty years old. Examples of biomaterials include metals, ceramics and polymers. These biomaterials can be found in contact lenses, pacemakers, heart valves, orthopaedic devices and much more. Biomaterials that are employed in components implanted into the human body for replacement of diseased or damaged body parts. These materials must not produce toxic substances and must be compatible with body tissues.

Materials of the future

I. Smart materials

Smart materials also called intelligent or responsive materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli such as stress, moister, electric or magnetic fields, light, temperature, pH or chemical compounds.

Smart material system consists of a sensor and an actuator. The function of the sensor is to detect an input signal. The actuator performs a responsive and adaptive function. The actuator may be called upon to change shape, position, natural frequency or mechanical characteristics in response to changes in temperature, electric fields and magnetic fields.

Materials used as sensors include optical fibres, piezoelectric materials and micro electromechanical devices (MEMS).

Four types of materials are used for actuators. They are

1. Shape memory alloys: these are metals that after having been deformed, revert back to their original shapes when temperature is changed.
2. Piezo electric ceramics: These materials expand and contract in response to an electric field conversely they also generate and electric field when their dimensions are altered.
3. Magnetostriction materials. These materials also expand and contrast in response to magnetic fields.
4. Electro rheological and magneto rheological fluids. These are fluids that experience dramatic changes in viscosity upon the application of electric and magnetic fields respectively.

One type of smart system is used in helicopters to reduce aerodynamic cockpit noise that is created by the rotating rotor blades. Piezoelectric sensors inserted into the blades monitor blade stresses and deformations, feedback signals from these sensors are feed into a computer controlled adaptive devices which generates noise cancelling antinoise.

II. Nano engineered materials

To understand the structure of the material scientists usually adopt two approaches. One is called "top down" approach and the other is called "bottom up" approach. In the former approach what they do is studying large and complex structures and then to investigate the fundamental building blocks of structures. But after the advent of scanning tunnelling microscope (STM), the observation of atoms and molecules are possible. By using this possibility scientists started forming new structures of materials by carefully arranging atoms and molecules to get required properties. We call this as "bottom-up" approach. The study of the properties of these materials is termed "nano technology". Nano denotes the dimensions of these structural entities are of the order of nanometres (10^{-6}m). The size less than 100 nm are considered as nano materials. Carbon nanotube is an example for nano material. In the future undoubtedly we can say that nano engineered materials play a crucial role.

UNIVERSITY MODEL QUESTIONS

Section A

(Answer in two or three sentences)

Short answer questions

1. What is materials science?
2. What are the different branches of science involved in materials science?
3. What is the aim of study of materials science?
4. How does the study of materials science important?
5. Define the terms a) structure and b) properties of materials.

6. Draw a schematic diagram of the interrelationship between the four components of the discipline of materials science.
7. Which are the four components of the discipline of materials science?
8. Mention the three classifications of materials science.
9. What are composites materials?
10. What are metals?
11. What are ceramics?
12. What are polymers?
13. Give three examples for metals.
14. Give three examples for ceramic materials.
15. Give the names of any three polymeric materials.
16. What is a carbon fibre reinforced polymer (CFRP)?
17. What is the advantage of CFRP over glass fibre reinforced materials?
18. What are advanced materials?
19. What are biomaterials?
20. What are smart materials?
21. Define

    (a) sensor (b) actuators in smart materials.
22. Mention the two approaches scientists usually adopt to understand the structure of materials.

Section B

(Answer questions in a paragraph of about half a page to one page)

Paragraph / Problem type

1. Materials play an important role in our everyday lives. Justify.
2. Distinguish between the three forms of structures of materials.
3. Why do we study materials science?
4. Write down the properties of metals.
5. What are the properties of ceramics?

6. What are the properties of polymers?
7. Distinguish between metals, ceramics and polymers.
8. Write a brief note on advanced materials.
9. Give brief account of biomaterials.
10. Discuss briefly the components of smart materials.
11. Which are the four types of materials that are used for actuators?
12. Give a brief account of nanoengineered materials.
13. Explain the "bottom up" and bottom up approaches scientists usually adopt to understand the structure of the materials.

Section C

(Answer in about two pages)

Long answer type questions (Essays)

1. Classify materials and discuss their properties.
2. Discuss in detail about the materials of the future.
3. Give an account of nano engineered materials.

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